Bryophytes of urban industrial streetscapes in Victoria, Australia

A Floyed and M Gibson*

School of Life and Environmental Sciences, Deakin University, 221 Burwood Highway,
Burwood, Victoria 3125, *Email: maryg@deakin.edu.au

Abstract

The bryophyte floristics of industrial/commercial streetscapes of urban Victoria and the importance of various substrata to species richness were explored. Species richness was low compared to healthy natural environments. Thirty mosses from 14 families, and six liverworts, each from different families, were identified. Most species occurred at fewer than 30% of sites, showing the patchy nature of their distribution. Only three species occurred at more than half the sites. Markedly higher species richness occurred on soil than on any other substratum. Epiphytes were extremely few. The low bryodiversity of streetscapes, the patchy nature of the bryophytes and the high number of colonists suggest that the streetscapes have not fulfilled their potential in providing connectivity between urban and non-urban areas. Colonists characteristically occur early in the successional sequence of disturbed areas but, as streetscapes are continually disturbed, colonists effectively are climax species for this habitat. Better management of streetscapes to provide more complex habitat is needed to enable colonisation of these areas by bryophyte species that are more representative of our ever-shrinking natural habitats. (*The Victorian Naturalist* **129** (6) 2012, 203-214).

Key words: Bryophytes, urban, streetscapes, substratum, connectivity

Introduction

Biodiversity conservation is a global concern and there is a growing recognition that urban environments can play an important role (Savard *et al.* 2000). Indeed, scientific research in urban ecology has become a global focus (Porter *et al.* 2001). Most studies have concentrated on areas with remnant native vegetation that have become surrounded by the urban matrix and set aside as public reserves or parks. But the urban environment consists of a wide range of 'green space'—everything in cities that has vegetation (Brennan and O'Connor 2008)—including the front and back yards of homes in residential areas, football ovals, golf courses, riparian strips and streetscapes, to name but a few. Streetscapes collectively make up a large component of the urban environment and have potential for mitigating some of the impacts of urbanisation on native biodiversity. Maximum potential can be achieved only with careful management that considers the ecology of streetscapes.

The term 'streetscape' as used in the context of this paper refers to exterior public spaces located between the vehicular carriageway and privately owned property or between the vehicular carriageway and public property not deemed part of the road infrastructure, e.g. library, law court, park. The exterior walls of any building or fence separating public from private land are included in the definition as they also provide habitat for plants. Streetscapes (Fig. 1) can consist of footpaths/walkways, walls of a fence or building, and sections of land ('nature strips') separating the footpath/walkway from the road or adjacent property. The nature strips may be found in any stage of development, from barren soil through to completely landscaped gardens. Currently, there are no studies published that have investigated the bryophyte populations of urban streetscapes within Australia. This paper examines bryophyte distribution of streetscapes in Victoria, Australia, but focuses on streetscapes where arsenic is known to be released into the atmosphere as it forms part of a larger study investigating the effects of arsenic on bryophytes. Elsewhere in the world, streetscapes have been included in larger studies (Giordano *et al.* 2004; Grdovic and Stevanovic 2006) that examined the bryophyte flora of cities, but such studies are comparatively few.

As our natural areas shrink due to increasing urbanisation, streetscapes *could* provide important habitat for flora and fauna as well as provide connectivity to remnant vegetation. Bryophytes are important components of natural habitats and are vital to ecosystem functioning. They are known to play various roles in:

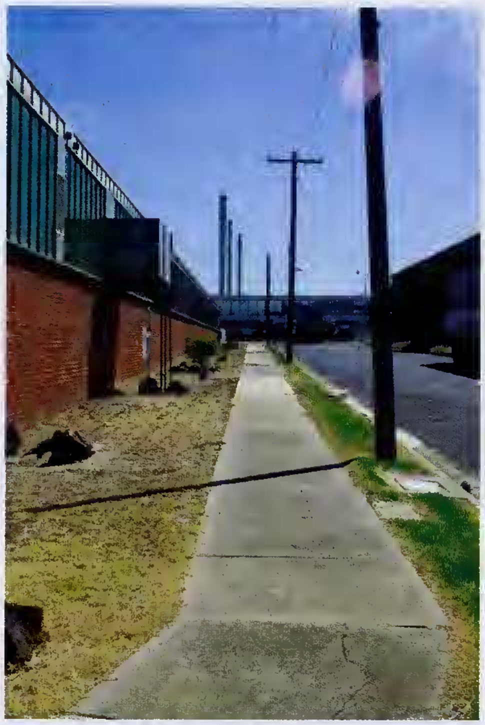


Fig. 1. An urban industrial streetscape.

primary and secondary succession (Hosokawa and Kubota 1957; Dilks and Proctor 1974; Bewley 1979; Proctor 1981; Furness and Grime 1982; Hearnshaw and Proctor 1982; Longton 1984; During 1992; Longton 1992; Breuil-See, 1993; Gibson 2006); soil formation (Longton 1984; Sveinbjornsson and Oechel 1992); water retention of soil (Moore and Scott 1979; Jarman and Kantvilas 1995); prevention of soil erosion by wind or water (Rogers and Lange 1971, 1972; Eldridge and Tozer 1996, 1997; Gibson 2006); nutrient cycling (Longton 1984; Rodgers and Henriksson 1976); nitrogen fixation (Rodgers and Henriksson 1976); the food web (Gerson 1969, 1982); provision of shelter and protection for invertebrates (Gerson 1969, 1982; Longton 1984; Davidson *et al.* 1990; Richardson 1991; Milne *et al.* 2006); provision of nesting materials for birds or rodents (Gerson 1982; Longton 1984); and provision of oviposit sites for invertebrates (Gerson 1982). The ecological role of bryophytes does not stop within urban regions, yet this area of study largely has been ignored by science. To understand the ecological importance of bryophytes in urban regions, a knowledge of which species occur and where would be helpful. This, sadly, is lacking for Australia.

This paper describes bryophyte floristics of industrial streetscapes within Melbourne, Geelong and Ballarat. The aims of the study were to determine:

1. what bryophyte species occur on industrial/commercial streetscapes of urban Victoria, and which are most widespread;
2. what families and genera occur and which are best represented; and
3. which substratum is most important in terms of providing greatest species richness.

It is hypothesised that a major component of the bryoflora will be common and widespread species, particularly colonists and fugitives. Both have comparatively short life spans and are common in disturbed habitats. Colonists expend much energy on both sexual and asexual reproduction (During 1979); fugitives in sexual reproduction (During 1979). Many small, long-lived spores are characteristic of both life strategies. The Pottiaceae and Bryaceae are predicted to be the most common and widespread families. Both families include cosmopolitan species common to urban regions (Gerdol *et al.* 2002; Aceto *et al.* 2003) and harsh environments. Soil is hypothesised to have the highest species richness. Soil is a common substratum on streetscapes as are trees, but epiphytes often are few in highly urbanised regions (Bates *et al.* 2001).

Methods

Study sites

As the work presented in this paper formed part of a larger project investigating the interaction of urban bryophytes with airborne arsenic, sites were restricted to those where arsenic was known to be released into the atmosphere. These sites were obtained from Australia's National Pollutant Inventory (NPI) database published by the Department of Environment and Heritage (http://www.npi.gov.au). Most sites occurred in industrial zones although some were in commercial zones (e.g. VH Operations in Parkville). Each site comprised of the streetscape surrounding a business, be it industrial or commercial, which released arsenic into the atmosphere. Seventy sites were located within the Melbourne Metropolitan Area and surrounding suburbs, 16 sites were located within the Geelong area while the remaining two sites were in the city of Ballarat (Fig. 2). Annual arsenic emissions at sites ranged from 0.0019 to 120 kg based on figures reported in the NPI database.

Study sites are temperate with strong seasonal variations in temperature. Mean minimum and maximum daily temperatures were respectively: summer 13.9°C and 25.3°C; autumn 10.8°C and 20.3°C; winter 6.5°C and 14.1°C; spring 9.5°C and 19.5°C (Australian Bureau of Meteorology [BOM] [http://www.bom.gov.au/climate]). Mean monthly rainfall for summer, autumn, winter and spring was 49.1, 47.8, 47.0 and 56.5 mm respectively.

Bryophytes were collected in each season of 2004 from all available substrata along the perimeter of each site, where possible. The types of substrata a species occurred on were noted. Substrata were placed into the following categories:

1. trees;
2. gravel: species collected actually grew on soil between the gravel but this type of substratum is very different from soil without gravel because of movement of the gravel, hence we have kept the two as distinct entities;
3. rocks, which formed part of the landscaping at sites;
4. asphalt;
5. cement; and
6. soil, either exposed or with grass.

Identification

Bryophyte samples were collected from each site and returned to the laboratory for identification. Extreme care was taken when removing bryophytes from their substratum. Only a representative portion of each species was collected, ensuring minimal disturbance so that the colony would continue to grow.

Samples were identified to species level where possible using an Olympus SZ-PT dissecting microscope and an Olympus BH-2 compound microscope. Terminology and nomenclature followed that of Streimann and Klazenga (2002) for mosses and McCarthy (2003) for liverworts.

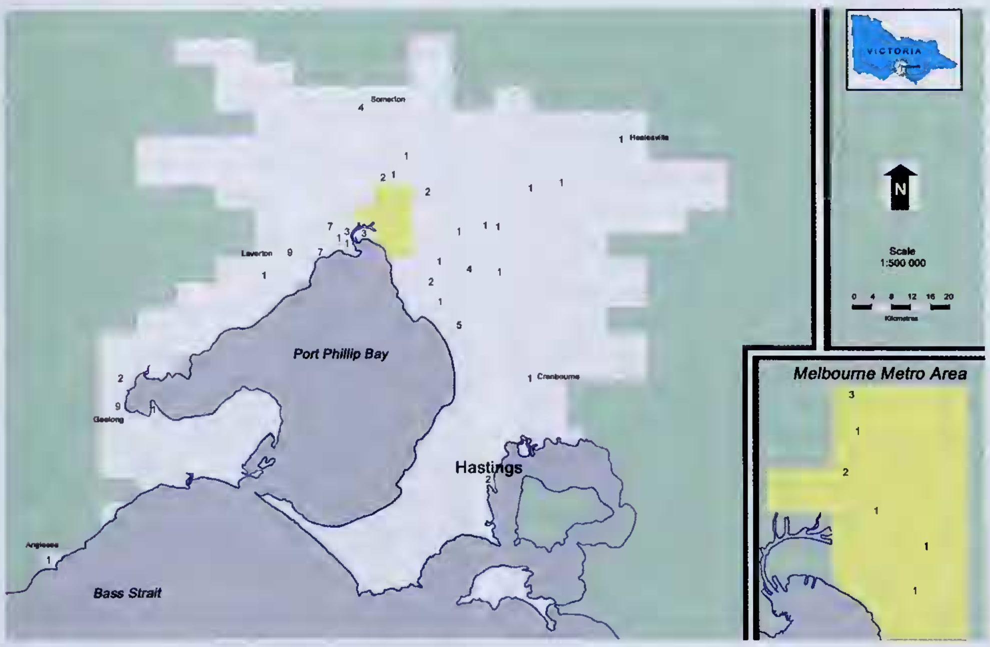


Fig. 2. Study sites of the Melbourne and Geelong urbanised regions. Numbers indicate the number of streetscapes examined in each locality.

Representative samples of each bryophyte were compared to voucher specimens held in the National Herbarium (Melbourne) for verification of identifications. Samples were lodged in the Deakin University herbarium (Melbourne Campus).

Results

Thirty-six species were identified (Table 1). Thirty species from 14 families were mosses; the remaining six species were liverworts, all from different families (Table 1). The best represented moss families were the Bryaceae and Pottiaceae with five and nine species respectively (Table 1). These two families occurred most frequently, i.e. at over 80% of the study sites (Fig. 3). The Fissidentaceae were represented by three species while the Ditrichaceae and Leucobryaceae each were represented by two species. The other moss families were represented by only one species. Two liverwort species could not be identified beyond genus.

Three moss families occurred at more than half the sites (Fig. 3): Bryaceae at 71, Pottiaceae at 66 and Brachytheciaceae at 46. Two other families, the Ditrichaceae and Funariaceae, occurred at 20 or more sites, while another three families, Fissidentaceae, Plagiotheciaceae and Leucobryaceae, occurred at more than 10 sites. The remaining six families occurred at eight or fewer sites (Fig. 3). Three species, *Bryum dichotomum*, *Bryum argenteum* and *Brachythecium rutabulum*, occurred at more than 40 sites. Another five species occurred at more than 30 sites. All other mosses occurred at fewer sites, most at fewer than 30% of sites, showing the patchy nature of their distribution. The most frequently occurring liverwort was *Chiloscyphus semiteres* var. *semiteres* which occurred at only 13 sites (Fig. 3). Each remaining hepatophyte occurred at no more than six sites (Fig. 3).

Bryophytes colonised all of the substrata sampled (Table 2); however, the level of colonisation varied between and within the various study sites. The most commonly colonised surface was soil, with all bryophyte species collected having colonised this surface at least once (Table 2). This was understandable as soil was the most commonly occurring substratum (Fig. 4) and is normally used as a means of separating the road side edge from the pedestrian footpath. Only a very limited number of sites lacked soil as part of their streetscape. Nature strips were normally covered in a variety of grasses, with either one or more trees present. Nature strips varied, some were landscaped with something as little as a series of large rocks or boulders placed at random intervals while others were well maintained, planted gardens. Pedestrian footpaths most commonly were made from poured slabs of concrete or cement; however, in many areas with high foot traffic, asphalt was used.

More species colonised cement footpaths than asphalt (Table 2). Cement footpaths provided more areas for colonisation, primarily in the region between each of the poured slabs, and in cement cracks caused by either changes in temperature, or from changes in the soil topography under the footpath. The cement cracks trap soil thereby promoting bryophyte growth, provide protection from trampling, wind or other forms of erosion and, generally, stay moist for longer periods of time than the surrounding surface. The higher species diversity also may be attributed to the higher frequency of cement (47 sites) as a substratum for colonisation when compared to asphalt (13 sites) (Fig. 4). While gravel footpaths may help reduce soil erosion from wind and rain, the continuing movement of the gravel explains the lower numbers of species on this substratum as the movement would prevent many bryophytes from being able to colonise these areas (Table 2).

Epiphytes were the least common, being found at only one study site and consisting of only *Tortula papillosa*, which was found growing in the fissures produced by the bark of *Quercus alba* (Table 2). No other vascular plants had epiphytic bryophytes colonising them, even though vascular plants occurred at 55 of the study sites (Fig. 4). This, possibly, was because the species of vascular plants normally planted in Victorian urban areas do not usually host many bryophytes although, in natural habitats, bryophytes can be found at the base of trunks of these species, especially of older individuals. The majority of trees were either *Melaleuca* species or *Eucalyptus* species. Both genera consisted of species that shed their bark on an almost constant basis, making it difficult for bryophytes to establish permanent colonies.

Table 1. Mosses and liverworts (indicated by asterisks) of Melbourne, Geelong, and Ballarat streetscapes. Bryophytes are listed in order of the number of sites at which a family occurred.

Family	No. of sites where families occurred (n=88)	Species
Bryaceae	71	*Bryum argenteum* Hedw.
		Bryum dichotomum Hedw.
		Bryum pachytheca Müll.Hal.
		Rosulabryum billarderi (Schwägr.) J.R.Spence
		Rosulabryum capillare (Hedw.) J.R.Spence
Pottiaceae	66	*Barbula calycina* Schwägr.
		Barbula crinita Schultz
		Didymodon torquatus (Taylor) Catches.
		Leptodontium paradoxum I.G.Stone and G.A.M.Scott
		Tetrapterum cylindricum (Taylor) A.Jaeger
		Tortula muralis Hedw.
		Tortula papillosa Wilson
		Tortula truncata (Hedw.) Mitt.
		Triquetrella papillata (Hook.f. and Wilson) Broth.
Brachytheciaceae	46	*Brachythecium rutabulum* (Hedw.) Schimp.
Ditrichaceae	27	*Ceratodon purpureus* (Hedw.) Brid. subsp. *convolutus* (Reichardt) Burley
		Ditrichum difficile (Duby) M.Fleisch.
Funariaceae	20	*Funaria hygrometrica* Hedw.
Fissidentaceae	16	*Fissidens curvatus* var. *curvatus* Hornsch.
		Fissidens leptocladus Müll.Hal. ex Rodway
		Fissidens taylorii var. *taylorii* Müll.Hal
Leucobryaceae	14	*Campylopus clavatus* (R.Br.) Wilson
	15	*Campylopus introflexus* (Hedw.) Brid.
Plagiotheceae	14	*Acrocladium chlamydophyllum* (Hook.f. and Wilson) Müll.Hal. and Broth.
**Geocalycaceae*	13	*Chiloscyphus semiteres* (Lehm. and Lindenb.) Lehm. and Lindenb. var. *semiteres*
Hypnaceae	8	*Calliergonella cuspidata* (Hedw.) Loeske
Polytrichaceae	8	*Polytrichum juniperinum* Hedw.
**Ricciaceae*	8	*Riccia bifurca* Hoffm.
Thuidiaceae	7	*Thuidiopsis sparsa* (Hook.f. and Wilson) Broth.
Grimmiaceae	6	*Grimmia pulvinata* (Hedw.) Sm. var. *africana* (Hedw.) Hook.f. and Wilson
**Fossombroniaceae*	5	*Fossombronia* sp.
**Lunulariaceae*	3	*Lunalaria cruciata* (L.) Dumort.
Orthotrichaceae	3	*Macromitrium microstomum* (Hook. and Grev.) Schwägr.
Ptychomitriaceae	3	*Ptychomitrium australe* (Hampe) A.Jaeger
**Adelanthaceae*	2	*Jackiella curvata* E.A.Hodgs. and Allison
**Cephaloziaceae*	2	*Cephaloziella* sp.

Interestingly, *T. papillosa* was collected from only seven of the 88 sites (Fig. 3), yet it colonised the most substrata of any of the species sampled (Table 2). The most commonly occurring species normally colonised more than one substratum, with most of them colonising at least three, and up to four, substrata (Table 2).

Discussion

Bryophyte species richness of streetscapes was low compared to natural environments. For instance, Jarman and Kantvilas (1995) found 165 bryophytes within Cool Temperate Rainforest in Tasmania; Carrigan (2009) found 96 species on rocks in Victorian Rainforest streams; Dell and Jenkin (2006) noted 88 species within Blackwood forest from the Otway Ranges in Victoria; and Floyed and Gibson (2006) identified 32 species occurring on a single fern species, *Dicksonia antarctica* Labill., within Victorian Cool Temperate Rainforest. These areas are particularly wet and known for their high species richness and diversity. Drier areas are not so diverse. Steer (2005) found that Box-Ironbark forests and woodlands had a total of

Fig. 3. Species frequencies of mosses and liverworts (n=88).

Table 2. Presence (+) of mosses and liverworts on various substrata. Liverworts are indicated by an asterisk.

Species	Substrata					
	Trees	Gravel	Asphalt	Rocks	Cement	Soil
Tortula papillosa	+		+	+	+	+
Bryum dichotomum		+	+		+	+
Campylopus introflexus		+	+	+		+
**Chiloscyphus semiteres* var. *semiteres*		+			+	+
Rosulabryum billarderi		+		+	+	+
Barbula calycina			+	+	+	+
Barbula crinita			+	+		+
Bryum argenteum			+	+	+	+
Bryum pachytheca			+		+	+
Tortula muralis			+	+	+	+
Brachythecium rutabulum				+	+	+
Didymodon torquatus				+	+	+
Grimmia pulvinata var. *africana*				+	+	+
Triquetrella papillata				+	+	+
Ceratodon purpureus subsp. *convolutus*				+		+
Funaria hygrometrica				+		+
Polytrichum juniperinum				+		+
Ptychomitrium australe				+		+
Calliergonella cuspidata					+	+
Fissidens leptocladus					+	+
Leptodontium paradoxum					+	+
Macromitrium microstomum					+	+
Tetrapterum cylindricum					+	+
Tortula truncata					+	+
Campylopus clavatus						+
**Cephaloziella* sp.						+
Ditrichum difficile						+
Fissidens curvatus var. *curvatus*						+
Fissidens taylorii var. *taylorii*						+
**Fossombronia* sp.						+
**Jackiella curvata*						+
**Lunalaria cruciata*						+
**Riccia bifurca*						+
Rosulabryum capillare						+
Thuidiopsis sparsa						+
Total number of species	1	4	8	15	18	35
Number of sites with substratum	55	10	13	2	47	81

51 species. Revegetated woodland of agricultural land only had 24 species (Hattam 2007). These latter two studies were investigations of areas with much lower complexity than the earlier studies mentioned. Lower complexity of a habitat is generally considered to reduce species richness (Moser *et al.* 2002; Kostylev *et al.* 2005; Eriksson *et al.* 2006). The streetscapes investigated were of very low complexity so the paucity of bryophytes was not unexpected.

As predicted, the Bryaceae and Pottiaceae were well represented on the streetscapes. This has been reported in other studies (Gerdol *et al.* 2002; Aceto *et al.* 2003) and is not surprising as most species in these families were colonists. Indeed, half the species identified in the streetscapes were colonists: *Barbula calycina, B. crinita, Bryum pachytheca, B. argenteum, B. dichotomum, Campylopus clavatus, C. introflexus, Ceratodon purpureus* subsp. *convolutus, Didymodon torquatus, D. difficile, Grimmia pulvinata* var. *africana, Lunalaria cruciata, Polytrichum juniperinum, Rosulabryum billarderi, R. capillare, Tortula muralis, T. papillosa* and *T. papillata.* These species are characteristic of habitats that appear at unpredictable times and locations but which then last for several years (Moore and Scott 1979; Eldridge and Tozer 1996). They also tend to be cosmopolitan. If not cosmopolitan, they are widespread, occurring

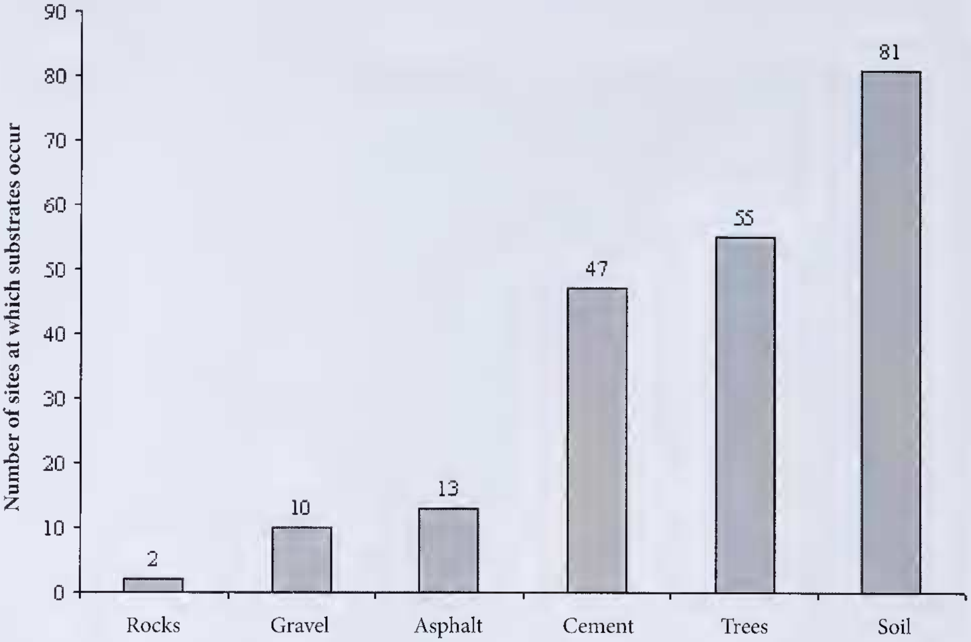


Fig. 4. Frequency of substrata at study sites (n=88).

in many different habitats. Such bryophytes expend a lot of energy on production of sexual and/or asexual propagules (During 1979) providing a resource for subsequent germination episodes either for the same area, if it remains disturbed, or for another disturbed area if propagules are distributed there. Streetscapes tend to be perpetually disturbed: when present, grass is mowed; there is high foot traffic; and trees or shrubs present are retained for their life span, thus there is no succession; road traffic causes high wind velocities close to the ground; and often soil is compacted so that flooding occurs with rain and desiccation in summer. Because of this, it is hardly surprising that so many species in streetscapes are colonists and found in harsh environments. *Funaria hygrometrica*, *P. juniperinum* and *Marchantia polymorpha*, for example, are primary colonisers after a fire (Bradbury 2006; Gibson 2006) and *Bryum argenteum*, *B dichotomum*, *Barbula calycina* and *Didymodon torquatus* commonly are found as part of soil crusts in arid and semi-arid habitats (Eldridge 1999).

Only one species, *Funaria hygrometrica*, had a fugitive life strategy, although some botanists class it as a colonist (http://www.anbg.gov.au). Fugitives characteristically occur in habitats that persist for short periods of time such as those occurring after fire (During 1979). Colonists occur in habitats that are disturbed but then remain for several years. All streetscapes examined have persisted for many years and the disturbances they experience are a 'natural' component of these ecosystems created by humans. In natural ecosystems, colonists may be pioneers in the successional story but, in the streetscapes examined, they also are the climax species.

Other bryophytes of streetscapes are more characteristic of a forest floor, for example, weft like species such as *Chiloscyphus semiteres* var. *semiteres* and *Brachythecium rutabulum* that form large open colonies in protected forests (Jarman and Kantvilas 2001; Downing *et al.* 2007); however, most of the streetscapes were not protected. *Brachythecium rutabulum* was the most common pleurocarpous species found in this study and is known to be tolerant of summer frosts (Rutten and Santarius 1992), which would help improve its ability to survive in open spaces such as streetscapes. It is a cosmopolitan species and common in both urban and woodland regions worldwide e.g. King's Lynn, UK (Stevenson and Hill 2008), Belgrade, Serbia (Sabovljevic and Grdovic 2009), South Lancashire, UK (Ashton 2003), Western Ghats, India (Manju *et al.* 2009) and Legnica, Poland (Samecka-Cymerman *et al.* 2009).

It was interesting to note that trees were present at 55 of the 88 sites studied but that only one bryophyte species (*T. papillosa*) was epiphytic, even though bryophytes are well known to be epiphytic. The trees planted consisted principally of bark-shedding *Melaleuca* and *Eucalyptus* species, thus it is understandable that few bryophytes were found on them. In non-urban regions of Australia, epiphytes generally form a much greater proportion of the species in an area. For instance, Steer (2005) found that 36 of the 51 species of bryophyte identified from Box-Ironbark Forest could be epiphytic; Pharo and Beattie (2002) identified 26 epiphytic bryophytes for sclerophyll forest in New South Wales; Floyed and Gibson (2006) found 32 species on *Dicksonia antarctica* Labill. in Cool Temperate Rainforest; however, Kellar *et al.* (2006) found only four bryophytes on *Eucalyptus regnans* F.Muell., a bark shedding tree, but found that *Nothofagus cunninghamii* was colonised by 12 species of bryophytes. There can be many reasons why there were few urban epiphytic bryophytes at the study sites. Firstly, there usually is a greater diversity of host species for bryophytes to colonise in forests. In urban areas, planting of trees is determined by what is most appealing, available and/or practical in an area, with no, or little, thought given for any ecological roles that they may play within the ecosystem they are introduced into (Parsons *et al.* 2006; Williams *et al.* 2006). Also, there are usually very few tree species planted along any streetscape, often only one or two species.

Secondly, trees planted on nature strips do not have the protection of surrounding forest trees, thus these urban trees will be subjected to stronger wind forces, greater extremes in temperature and higher light regimes. This means that bryophytes probably will have longer periods of being in a dried state than their forest counterparts. Also, epiphytes would be subjected to greater dust deposition, which would include pollutants. These factors make urban habitats more difficult to colonise and, subsequently, to survive in.

Thirdly, unless the streetscapes are connected to or in proximity to a source of propagules, colonisation by more patchily distributed bryophytes would be infrequent or would not occur at all. As it is, very few of the bryophytes of streetscapes were common, with 25 species occurring in less than 20 of the 88 study sites, and *all* the species identified in the study are classed as common and widespread in Australia (Meagher and Fuhrer 2003)!

The fissuring that occurs in the bark of *Quercus alba* is the most probable reason for colonisation of this particular tree by bryophytes; however, only one bryophyte species was found. Ashton and McRae (1970), Pike *et al.* (1975), Kantvilas and Minchin (1989), Peck *et al.* (1995) and Martin and Novak (1999) suggest that fissuring provides new habitats for development and increased growth rates, explaining high epiphytic diversity in non-urban trees with fissured bark. Such diversity did not occur in this study, suggesting that factors other than substratum have influenced the colonisation of bryophytes on this host.

Colonisation of cement pavements always occurred within the crevices between each pair of slabs of cement, or where the cement had cracked and lifted, providing a sheltered area for colonisation. Colonies normally extended large distances along these crevices, in some instances taking up the complete length of the crevice from one side of the pavement to the other. The species occurring within these microhabitats were predominantly small acrocarpous species, which trapped the soil that collected around their lower regions, forming a thin soil bed. Pleurocarpous species were not as common as acrocarpous species but could occur in well-developed colonies.

The most heavily colonised substratum was soil. This was not surprising, as other studies, although non-urban, also showed soil to have high species diversity (Eldridge and Tozer 1996; Floyed 1999; Floyed and Gibson 2006; Milne *et al.* 2006). Soil provided a wide range of microclimates, from exposed barren areas reminiscent of desert habitats, through to lush grass lawns, which offer greater protection from the elements and a greater level of water retention. Species composition appeared to be determined by what else grew on the soil. Pleurocarpus species of moss such as *Acrocladium chlamydophyllum* and *Brachythecium rutabulum* and the liverwort *Chiloscyphus semiteres* var. *semiteres* were found frequently growing amongst various grass species where conditions were quite wet, well shaded and provided a greater amount of protection from erosion by wind. Streetscapes where soil was shaded generally had a greater abundance of liverworts, but tended to be found only during the wetter periods of the year. While liverworts may well have been present in the soil propagule bank, they were found only after a rain incident or in areas with a continuous water supply adjacent to where they were found. Mosses, on the other hand, were found year-round under almost any types of conditions.

Concluding remarks

The low bryophyte diversity of streetscapes, the patchy nature of many species and the cosmopolitan distribution of many species has important conservation implications. Forests and other ecosystems are shrinking and becoming more fragmented as urban areas continue to spread. The streetscapes examined were simple habitats with very low complexity and were adjacent to industrial sites. Their low bryodiversity suggests an inability to support the species richness and diversity of more complex habitats such as forests and woodlands. The high number of colonists and cosmopolitan species indicates that urban expansion will result in the simplification of bryophyte communities, with rare species and later successional species likely to become locally extinct if provision is not made to set aside sufficient and appropriately managed parks for their survival. An optimistic hope is that streetscapes of non-industrial urban regions provide for a better bryodiversity, but this does not appear to be the case (pers. obs.).

Management of streetscapes has been suggested as a way of maintaining biodiversity and providing connectivity between forest fragments by White *et al.* (2005) who noted that streetscapes with similar vegetation types to those of closely associated parks of remnant forest had similar avian fauna, while streetscapes with exotic or limited flora had a decrease in both insectivorous and nectarivorous bird species. In terms of bryophytes, careful planning of streetscapes to provide more habitat complexity and flora indigenous to an area could provide for higher bryophyte diversity in urban areas and maintenance of species native to specific regions. Then streetscapes also would be more likely to provide a conduit for dissemination of bryophyte propagules from one region to another, allowing colonisation or recolonisation of an area by species other than those that are common and widespread.

References

Aceto M, Abollino O, Conca R, Malandrino M, Mentasti E and Sarzanini C (2003) The use of mosses as environmental metal pollution indicators. *Chemosphere* **50**, 333–342.

Ashton DH and McRae RF (1970) The distribution of epiphytes on beech (*Nothofagus cunninghamii*) trees at Mt. Donna Buang, Victoria. *The Victorian Naturalist* **87**, 253–261.

Ashton PA (2003) A new flora of v.c. 59 (South Lancashire): a progress report. *Watsonia* **24**, 351–357.

Bates JW, Bell JNB and Massara AC (2001) Loss of *Lecanora conizaeoides* and other fluctuations of epiphytes on oak in S.E. England over 21 years with declining SO_2 concentrations. *Atmospheric Environment* **35**, 2557–2568.

Bewley JD (1979) Physiological aspects of desiccation tolerance. *Annual Review of Plant Physiology* **30**, 195–238.

Bradbury SM (2006) Response of the post-fire bryophyte community to salvage logging in boreal mixed wood forests of northeastern Alberta, Canada. *Forest Ecology and Management* 234, 313–322.

Brennan C and O'Connor D (2008) *Green city guidelines: advice for the protection and enhancement of biodiversity in medium to high-density urban developments*. (UCD Urban Institute: Ireland)

Breuil-Seé A (1993) Recorded desiccation-survival times in bryophytes. *Journal of Bryology* **17**, 679–680.

Carrigan CM (2009) Stream bryophytes of Victorian temperate rainforests. (Unpublished PhD thesis, Deakin University)

Davidson AJ, Harborne JB and Longton RE (1990) The acceptability of mosses as food for generalist herbivores, slugs in the Arionidae. *Botanical Journal of the Linnean Society* **104**, 99–113.

Dell M and Jenkin J (2006) Bryophyte distribution in Blackwood forests on the Otway Ranges, Victoria. *The Victorian Naturalist* **123**, 255–269.

Dilks TJK and Proctor MCF (1974) The pattern of recovery of bryophytes after desiccation. *Journal of Bryology* **8**, 97–115.

Downing AJ, Brown EA, Oldfield RJ, Selkirk PM and Coveny R (2007) Bryophytes and their distribution on the Blue Mountains region of New South Wales. *Cunninghamia* **10**, 225–254.

During HJ (1979) Life strategies of bryophytes: a preliminary review. *Lindbergia* **5**, 2–18.

During HJ (1992) Ecological classifications of bryophytes and lichens. In *Bryophytes and lichens in a changing environment*, pp. 1–31. Eds JW Bates and AM Farmer. (Clarendon Press: Oxford)

Eldridge DJ (1999) Distribution and floristics of moss- and lichen-dominated soil crusts in a patterned *Callitris glaucophylla* woodland in eastern Australia. *Acta Oecologica* **20**, 159–170.

Eldridge DJ and Tozer ME (1996) Distribution and floristics of bryophytes in soil crusts in semi-arid and arid eastern Australia. *Australian Journal of Botany* **44**, 223–247.

Eldridge DJ and Tozer ME (1997) Environmental factors relating to the distribution of terricolous bryophytes and lichens in semi-arid eastern Australia. *The Bryologist* **100**, 28–39.

Eriksson BK, Rubach A and Hillebrand H (2006) Biotic habitat complexity controls species diversity and nutrient effects on net biomass production. *Ecology* **87**, 246–254.

Floyed AB (1999) Bryophyte communities of selected Rainforests within Victoria. (Unpublished Honours thesis, Deakin University)

Floyed AB and Gibson M (2006) Epiphytic bryophytes of *Dicksonia antarctica* Labill. from selected pockets of Cool Temperate Rainforest, Central Highlands, Victoria. *The Victorian Naturalist* **123**, 229–235.

Furness SB and Grime JP (1982) Growth rate and temperature responses in bryophytes II. A comparative study of species of contrasted ecology. *Journal of Ecology* **70**, 525–536.

Gerdol R, Bragazza L, Marchesini R, Medici A, Pedrini P, Benedetti S, Bovolenta A and Coppi S (2002) Use of moss (*Tortula muralis* Hedw.) for monitoring organic and inorganic air pollution in urban and rural sites in Northern Italy. *Atmospheric Environment* **36**, 4069–4075.

Gerson U (1969) Moss-arthropod associations. *The Bryologist* **72**, 495–500.

Gerson U (1982) Bryophytes and invertebrates. In *Bryophyte ecology*, pp. 291–332. Ed AJE Smith. (Chapman and Hall: London)

Gibson M (2006) Introducing bryophytes. *The Victorian Naturalist* **123**, 192–194.

Giordano S, Sorbo S, Adamo P, Basile A, Spagnuolo V and Cobianchi RC (2004) Biodiversity and trace element content of epiphytic bryophytes in urban and extraurban sites of southern Italy. *Plant Ecology* **170**, 1–14.

Grdovic S and Stevanovic V (2006) The moss flora in the central urban area of Belgrade. *Archives of Biological Sciences* **58**, 55–59.

Hattam JS (2007) Regeneration of the bryoflora of the Dundas Tablelands, Western Victoria. (Unpublished Honours thesis, Deakin University)

Hearnshaw GF and Proctor MCF (1982) The effects of temperature on the survival of dry bryophytes. *New Phytologist* **90**, 221–228.

Hosokawa T and Kubota H (1957) On the osmotic pressure and resistance to desiccation of epiphytic mosses from a beech forest, south-west Japan. *Journal of Ecology* **45**, 579–591.

Jarman SJ and Kantvilas G (1995) Epiphytes on an old Huon pine tree (*Lagarostrobos franklinii*) in Tasmanian rainforest. *New Zealand Journal of Botany* **33**, 65–78.

Jarman SJ and Kantvilas G (2001) Bryophytes and lichens at the Warra LTER Site. II. Understorey habitats in *Eucalyptus obliqua* wet sclerophyll forest. *Tasforests* **13**, 217–243.

Kantvilas G and Minchin PR (1989) An analysis of epiphytic lichen communities in Tasmanian cool temperate rainforest. *Vegetatio* **84**, 99–112.

Kellar C, Short M and Milne J (2006) Epiphytes on *Nothofagus cunninghamii* and *Eucalyptus regnans* in a Victorian cool temperate rainforest. *The Victorian Naturalist* **123**, 222–227.

Kostylev VE, Erlandsson J, Ming MY and Williams GA (2005) The relative importance of habitat complexity and surface area in assessing biodiversity: Fractal application on rocky shores. *Ecological Complexity* **2**, 272–286.

Longton RE (1984) The role of bryophytes in terrestrial ecosystems. *Journal of the Hattori Botanical Laboratory* **55**, 147–163.

Longton RE (1992) The role of bryophytes and lichens in terrestrial ecosystems. In *Bryophytes and lichens in a changing environment*, pp. 32–76. Eds JW Bates and AM Farmer. (Oxford Science Publishing: New York)

Manju CN, Rajesh KP and Madhusoodanan PV (2009) Contribution to the bryophyte flora of India: the Aralam Wildlife Sanctuary in the Western Ghats. *Archive for bryology* **42**, 1–12.

Martin E and Novak SJ (1999) Composition and cover of epiphytic lichens on *Pseudotsuga menziesii* and *Populus tremuloides* in southwestern Idaho. *Evansia* **16**, 105–111.

McCarthy PM (2003) *Catalogue of Australian liverworts and hornworts*. (ABRS: Canberra)

Meagher D and Fuhrer B (2003) *A field guide to the mosses and allied plants of southern Australia*. (Australian Biological Resources Study and The Field Naturalists Club of Victoria: Canberra)

Milne J, Short M and Beckmann K (2006) A preliminary study of bryophytes and invertebrates of soil crusts in the Little Desert National Park and surrounds. *The Victorian Naturalist* **123**, 195–203.

Moore CJ and Scott GAM (1979) The ecology of mosses on a sand dune in Victoria, Australia. *Journal of Bryology* **10**, 291–311.

Moser D, Zechmeister HG, Plutzar C, Sauberer N, Wrbka T and Grabherr G (2002) Landscape patch shape complexity as an effective measure for plant species richness in rural landscapes. *Landscape Ecology* **17**, 657–669.

Parsons H, Major RE and French K (2006) Species interactions and habitat associations of birds inhabiting urban areas of Sydney, Australia. *Austral Ecology* **31**, 217–227.

Peck JE, Hong WS and McCune B (1995) Diversity of epiphytic bryophytes on three host tree species, Thermal Meadow, Hotsprings Island, Queen Charlotte Islands, Canada. *The Bryologist* **98**, 123–128.

Pharo EJ and Beattie AJ (2002) The association between variability and bryophyte and lichen diversity in eastern Australian forests. *The Bryologist* **105**, 1–26.

Pike LH, Devinson WC, Tracey DM, Sherwood MA and Rhoades FM (1975) Floristic survey of epiphytic lichens and bryophytes growing on old-growth conifers in western Oregon. *The Bryologist* **78**, 389–402.

Porter EE, Forschner BR and Blair RB (2001) Woody vegetation and canopy fragmentation along a forest-to-urban gradient. *Urban Ecosystems* **5**, 131–151.

Proctor MCF (1981) Physiological ecology of bryophytes. In *Advances in Bryology*, pp. 80–166. Ed W Schultze-Motel. (Strauss and Cramer: Germany)

Richardson DHS (1991) Lichens as biological indicators - recent developments. In *Bioindicators and environmental management*, pp. 263–271. Eds DW Jeffery and B Madden. (Academic Press: Sydney)

Rodgers GA and Henriksson E (1976) Associations between the blue-green algae *Anabaena variabilis* and *Nostoc muscorum* and the moss *Funaria hygrometrica* with reference to the colonization of Surtsey. *Acta Botanica Islandica* **4**, 10–15.

Rogers RW and Lange RT (1971) Lichen populations on arid soil crusts around sheep watering places in South Australia. *Oikos* **22**, 93–100.

Rogers RW and Lange RT (1972) Soil surface lichens in arid and subarid south-eastern Australia. *Australian Journal of Botany* **20**, 197–213.

Rutten D and Santarius KA (1992) Relationship between frost tolerance and sugar concentration of various bryophytes in summer and winter. *Oecologia* **91**, 260–265.

Sabovljevic M and Grdovic S (2009) Bryophyte diversity within urban areas: Case study of the city of Belgrade (Serbia). *International Journal of Botany* **5**, 85–92.

Samecka-Cymerman A, Stankiewicz A, Kolon K and Kempers AJ (2009) Bioindication of trace metals in *Brachythecium rutabulum* around a copper smelter in Legnica (Southwest Poland): use of a new form of data presentation in the form of a self-organizing feature map. *Archives of Environmental Contamination and Toxicology* **56**, 717–722.

Savard JPL, Clergeau P and Mennechez G (2000) Biodiversity concepts and urban ecosystems. *Landscape and Urban Planning* **48**, 131–142.

Steer RJ (2005) The relationship between ecological vegetation classification and bryophyte diversity in the box-ironbark forests and woodlands of Victoria, Australia. (Unpublished Honours thesis, Deakin University)

Stevenson CR and Hill MO (2008) Urban myths exploded: results of a bryological survey of King's Lynn (Norfolk, UK). *Journal of Bryology*, **30**, 12–22.

Streimann H and Klazenga N (2002) *Catalogue of Australian mosses.* (Australian Biological Resources Study: Canberra)Sveinbjornsson B and Oechel WC (1992) Controls on growth and productivity of bryophytes: environmental limitations under current and anticipated conditions. In *Bryophytes and lichens in a changing environment*, pp. 78–102. Eds JW Bates and AM Farmer. (Clarendon Press: Oxford)

White JG, Antos MJ, Fitzsimons JA and Palmer GC (2005) Non-uniform bird assemblages in urban environments: the influence of streetscape vegetation. *Landscape and Urban Planning* **71**, 123–135.

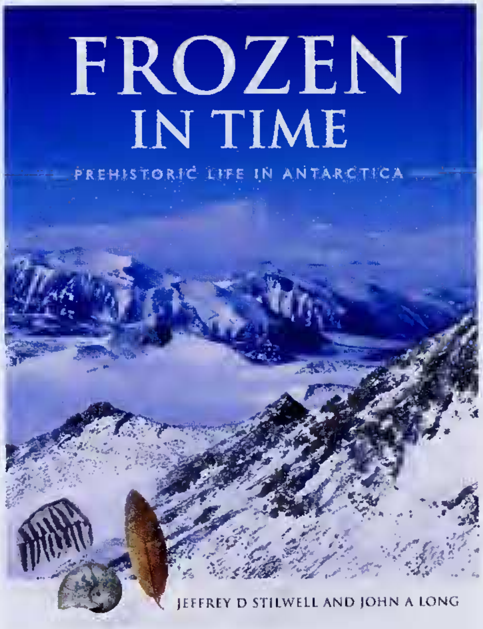
Williams NSG, McDonnell MJ, Phelan GK, Keim LD and Van Der Ree R (2006) Range expansion due to urbanization: Increased food resources attract Grey-headed Flying-foxes (*Pteropus poliocephalus*) to Melbourne. *Austral Ecology* **31**, 190–198.

Received 12 July 2012; accepted 20 September 2012

Frozen in Time: Prehistoric Life in Antarctica

by Jeffrey D Stilwell and John A Long

Publisher: *CSIRO Publishing, Collingwood, Victoria, 2011. 248 pages, hardback, colour illustrations. ISBN 9780643096356. RRP $69.95*



To try to tell the story of life on any of the Earth's continents in a single volume would be a daunting challenge. To illustrate the life-story of a continent, 98% of which is covered with ice up to 5 km thick, would seem impossible.

This is what Dr Jeffrey Stilwell and Professor John Long, the authors of *Frozen in Time: Prehistoric Life in Antarctica*, have set out to do and, in my opinion, they have succeeded brilliantly. This beautifully produced and profusely illustrated 238-page volume provides readers with almost everything they need to know about Antarctica's fascinating life history and, should they wish to explore farther, its 33 pages of further reading references provide an invaluable research guide.

We know little about Antarctic life during the first four billion years of Earth history (Precambrian Eon). Now, thanks to scientific discoveries by innumerable expeditions over the past century, we know that Antarctica has not always been ice-bound. For most of the time since the Cambrian Period, 540 million years ago, Antarctica has supported rich and diverse plant and animal life and has undergone major climatic changes.

By combining their different skills and expertise (Stilwell in ancient environments and Long in the evolution of vertebrates) and their first-hand experience of different parts of Antarctica, the authors trace its history in a comprehensive, well-illustrated review based on its fossil record.